$|V_{cb}|$ and $|V_{ub}|$ measurements at Belle

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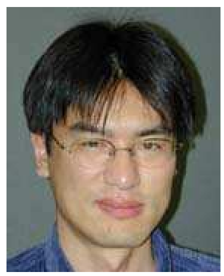


In this paper, we report on the results of the $|V_{cb}|$ and $|V_{ub}|$ measurements obtained from studies of inclusive and exclusive semileptonic decays using 30fb^{-1} of e^+e^- collision data collected by the Belle detector at KEKB.

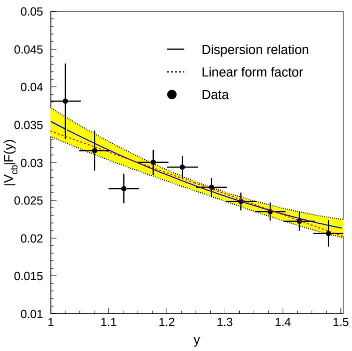
1 Introduction

The CKM matrix [1] whose elements have to be determined through experiments is expressed using the Wolfenstein parameters as:

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix} \tag{1}$$

A precise determination of $|V_{cb}|$ is important since some tests of the CKM framework is sensitive to $|V_{cb}|$; for example, the CP violation parameter $|\varepsilon_K|$ which constrains the apex position of the CKM unitary triangle in the $\rho-\eta$ plane is proportional to A^4. In addition, an accurate measurement of $|V_{ub}|$ is also of importance because CP violation does not occur in the framework of the minimal Standard Model if $|V_{ub}|$ is zero.

In this paper, we present $|V_{cb}|$ and $|V_{ub}|$ measurements from inclusive and exclusive semileptonic decays of B mesons using e^+e^- collision data collected by the Belle detector at KEKB. The Belle detector consists of a silicon vertex detector (SVD), a central drift chamber (CDC), aerogel cherenkov counters (ACC), time of flight counters (TOF), electromagnetic calorimeters (ECL) and a KLM detector which detects K_Ls and muons. The SVD and the CDC perform tracking and momentum measurements of charged particles. With the dE/dx measurements in the CDC, the TOF and the ACC provide separation of pions and kaons in the momentum



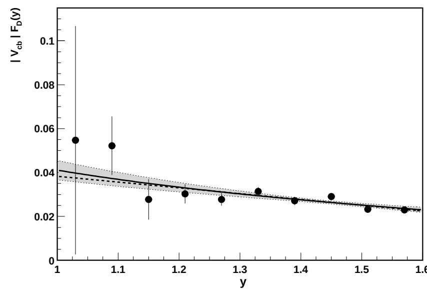


Figure 1: Distributions of $D^{*+}e^-\bar{\nu}_e$(left) and $D^+\ell^-\bar{\nu}$(right) decay mode, respectively. Fitted results are also shown.

range up to $4\text{GeV}/c$. Electrons are identified with combined information from the ECL, CDC, ACC and TOF, and muons are identified with the KLM. A 1.5T magnetic field is provided by a superconducting solenoid magnet located inside the KLM.

2 $|V_{cb}|$ measurements

2.1 $|V_{cb}|$ from exclusive decays

The recent development of Heavy Quark Effective Theory (HQET) [2] provides us an expression of the differential decay rate of $B \to D^{(*)}\ell\nu$ as a function of y, where y is the inner product of 4-velocities of B and $D^{(*)}$, with a form factor at the zero recoil point ($y = 1$) whose uncertainty is theoretically controllable and the determination of $|V_{cb}|$ with the smallest theoretical error.

We analyzed $\bar{B}^0 \to D^{*+}e^-\bar{\nu}_e$ decay mode [3] with the subdecay of $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ using 10.2fb^{-1} data. Since in the final state there is an undetectable neutrino, we used a partial reconstruction method; we imposed a kinematical constraint on missing invariant mass defined as $M_{miss} \equiv (P_B - P_{D^*e})^2$, where P_B and P_{D^*e} are 4 momentum vectors of the B and the $D^{*+}e^-$ system, respectively.

We also studied the decay [4] of $\bar{B}^0 \to D^+\ell^-\bar{\nu}$, where the D^+ subsequently decays into $K^+\pi^+\pi^-$. In this decay mode, we applied a full neutrino reconstruction method; in each event we extracted information on the neutrino from the missing momentum ($\vec{p}_{miss} = \sum_i \vec{p_i}$) and missing energy ($E_{miss} = \sum_i E_i$), where the summation is carried out for all reconstructed particles, and required $M^2_{miss} = E^2_{miss} - |\vec{p}_{miss}|^2 \simeq 0$.

In both decay modes, the dominant background comes from combinatorical background in $D^{(*)}$ reconstruction. It was estimated from the sideband data of the $D^{(*)}$ invariant mass distributions.

After subtracting backgrounds, correcting efficiency and unfolding the smearing, we obtained y distributions of each decay mode as shown in figure 1. With the measured y distributions, we fitted $|V_{cb}|F(1)$ ($F(1)$ is the form factor at the zero recoil point) and ρ^2 which is a single parameter determining the shape of the differential decay rate function. We obtained $|V_{cb}|F_{D^*}(1) = (3.54 \pm 0.19 \pm 0.18) \times 10^{-2}$ and $|V_{cb}| = (3.88 \pm 0.21 \pm 0.20 \pm 0.19) \times 10^{-2}$ using $F_{D^*}(1) = 0.913 \pm 0.042$ [5] for $\bar{B}^0 \to D^{*+}e^-\bar{\nu}_e$, $|V_{cb}|F_D(1) = (4.11 \pm 0.44 \pm 0.52) \times 10^{-2}$ and $|V_{cb}| = (4.19 \pm 0.45 \pm 0.53 \pm 0.30) \times 10^{-2}$ using $F_D(1) = 0.98 \pm 0.07$ [6] for $\bar{B}^0 \to D^+\ell^-\bar{\nu}$, where the errors are statistical, systematic and theoretical in order. By integrating the y distributions, we estimated the branching ratio to be $Br(\bar{B}^0 \to D^{*+}e^-\bar{\nu}_e) = (4.59 \pm 0.23 \pm 0.40) \times 10^{-2}$ and $Br(\bar{B}^0 \to D^+\ell^-\bar{\nu}) = (2.13 \pm 0.12 \pm 0.39) \times 10^{-2}$.

2.2 $|V_{cb}|$ from inclusive decays

$|V_{cb}|$ is also obtained from the measurements of branching ratio of inclusive semileptonic decays using formulas based on the heavy quark expansion [7]. In this analysis, a high momentum lepton tag method was employed, i.e. we tagged a high momentum lepton from the decay of one of two B mesons and observed the lepton (the electron in this analysis) from the decay of the other B meson. Using the charge and kinematical correlations between the tagged lepton and the electron, primary electrons can be distinguished from the secondary charm decay electrons which are the main background. With 5.1fb^{-1} data, the branching ratio was measured to be $Br(B \to Xe\nu) = (10.90 \pm 0.12(stat.) \pm 0.49(syst.)) \times 10^{-2}$. After subtracting the charmless semileptonic fractions with an assumption of $Br(b \to u\ell\nu) = (0.167 \pm 0.055)\%$ and using the world average B lifetime of 1.607 ± 0.021ps, we estimated $|V_{cb}|$ to be $(4.08 \pm 0.10 \pm 0.25) \times 10^{-2}$, where the first uncertainty includes statistical and systematic errors and the second one is the theoretical error. The $|V_{cb}|$ value obtained from the inclusive semileptonic decay analysis is quite consistent with those from exclusive decays.

3 $|V_{ub}|$ measurements

3.1 $|V_{ub}|$ from $B \to \pi\ell\nu$

The exclusive decay $\bar{B}^0 \to \pi^+\ell^-\bar{\nu}$ is one of the most promising modes for measuring $|V_{ub}|$. From the branching ratio of the decay, $|V_{ub}|$ is evaluated using formula $Br(\bar{B}^0 \to \pi^+\ell^-\bar{\nu}) = \gamma_\pi |V_{ub}|^2 \tau_B$, where γ_π is a factor determined by a model and τ_B is the B meson lifetime. To extract the decay events, we applied the same full neutrino reconstruction method as employed in the $B \to D\ell\nu$ study and used a 29.2fb^{-1} data sample. Events which have only one lepton whose momentum ranges from 1.2 to 2.8GeV/c in the $\Upsilon(4S)$ rest frame were selected. For suppressing $B\bar{B}$ generic decay events which are one of the dominant backgrounds, we also required $P_\ell + P_\pi > 3.1$GeV/c, since the signal π's have much higher momenta than those from the background. By fitting $\Delta E (= E_{beam} - (E_\pi + E_\ell + E_\nu))$ and lepton momentum distributions simultaneously, we obtained 770 signal events. We adopted two models for estimating the branching ratio and $|V_{ub}|$. The results are summarized in Table 1.

Table 1: Measured branching ratios (B.R.) and $|V_{ub}|$ with two models. The errors are statistical, systematic and theoretical in order.

Model	B.R.	γ_π	$\lvert V_{ub}\rvert$
LCSR [8]	$(1.89 \pm 0.15 \pm 0.30) \times 10^{-4}$	7.3 ± 2.5	$(4.09 \pm 0.17 \pm 0.33 \pm 0.76) \times 10^{-3}$
UKQCD [9]	$(1.92 \pm 0.16 \pm 0.30) \times 10^{-4}$	$9^{+3}_{-2} \pm 2$	$(3.71 \pm 0.15 \pm 0.29 \pm 0.67) \times 10^{-3}$

3.2 Analysis of $B \to D_s\pi$

$|V_{ub}|$ can be extracted from the branching ratio of the hadronic decay $B^0 \to D_s^+\pi^-$ using a theoretical prediction [10] $Br(B^0 \to D_s^+\pi^-) = (2.6 \sim 5.2) \times |V_{ub}^* V_{cs}|^2$. Although the prediction has a large uncertainty, experimental extraction of the signal events is straightforward since signal Bs can be fully reconstructed. To search events, we reconstructed D_s^+ subsequently decaying to $\phi(\to K^+K^-)\pi^+$, $K^0(\to \pi^+\pi^-)K^+$ and $K^{*0}(\to K^+\pi^-)K^+$ (note that the main contribution of systematic errors come from the uncertainties of D_s^+ decay branching ratios $(25 \sim 30\%)$). Figure 2 shows $\Delta E (= E_{D_s} + E_\pi - E_{beam})$ distributions for each D_s^+ decay mode obtained using 29.2^{-1} data. The blank histograms are data in the signal region and the shaded histograms are the sideband data. Table 2 shows reconstruction efficiencies, numbers of yield in the signal region and backgrounds estimated from the sideband data and obtained upper limits

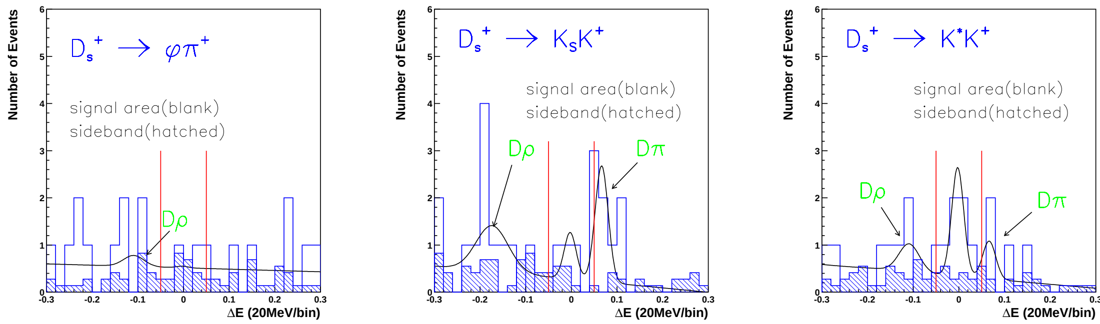


Figure 2: ΔE distributions for each D_s^+ decay mode: from left to right, D_s^+ to $\phi\pi^+$, K_sK^+ and $K^{*0}K^+$. The blank histograms are data in the signal region, while shaded histograms are sideband data.

at a 90% C.L. for the three D_s^+ decay modes. By combining the three modes, we obtained an upper limit of $Br(B^0 \to D_s^+\pi^-)$ to be 1.0×10^{-4} at a 90%C.L., which includes systematic errors.

Table 2: Reconstruction efficiencies (ε_{rec}), numbers of yield in the signal region and backgrounds estimated from the sideband data and upper limits at a 90% C.L. for the three D_s^+ decay modes.

Decay mode	ε_{rec}(%)	Yield(B.G.)	B.R.(90%C.L.)
$\phi\pi^+$	16.1	2 (2.6)	$< 0.5 \times 10^{-4}$
K^0K^+	12.3	5 (1.1)	$< 2.8 \times 10^{-4}$
$K^{*0}K^+$	8.6	6 (1.8)	$< 2.3 \times 10^{-4}$

4 Conclusion

From the exclusive semileptonic decay analysis, we determined $|V_{cb}|F_{D^*}(1) = (3.54 \pm 0.19 \pm 0.18) \times 10^{-2}$ and $|V_{cb}|F_D(1) = (4.11 \pm 0.44 \pm 0.52) \times 10^{-2}$. The branching ratio of inclusive semileptonic decays was measured to be $Br(B \to X\ell\nu) = (10.90 \pm 0.12 \pm 0.49) \times 10^{-2}$. By using two models, we estimated the branching ratio of $\bar{B}^0 \to \pi^+\ell^-\bar{\nu}$ and $|V_{ub}|$ as summarized in Table 1. We performed a search for $B^0 \to D_s^+\pi^-$ decays and obtained an upper limit of 1.0×10^{-4} at a 90% C.L.

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